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ORIGINAL ARTICLE

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Effect of prefabricated immediate interim prosthesis design and insertion workflow on seating accuracy on implants placed via static computer-assisted implant surgery: A cross-sectional in vitro study

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Abstract

Background: Immediate implant restoration by prefabricated prosthesis has multiple benefits. However, the design and insertion workflow of the prosthesis may influence the seating.

Purpose: Evaluation of seating accuracy of prefabricated interim prosthesis of different designs and insertion workflows for immediate restoration of implants placed via static computer-assisted implant surgery (sCAIS).

Materials and Methods: A maxillary model without incisors was used to plan for two implants at the lateral incisor locations. According to the planned implants, sCAIS surgical template and a four-unit interim prosthesis were designed. Four prostheses were fabricated based on the design and insertion workflow. The first prosthesis involved complete fabrication (CF) of the interim prosthesis, where the interim prosthesis is fabricated for laboratory attachment to abutments. The other three prostheses were produced by partial fabrication (PF), where the interim prosthesis shell was produced with internal spacing between the fitting surface and the abutments. The PF prostheses were cemented on abutments attached to the inserted implants. Three different PF prosthesis designs were included with different levels of internal spacing: 100 μm (PF.1), 200 μm (PF.2), and 300 μm (PF.3). A total of 15 surgical models received implants on which each prosthesis was seated and scanned by a laboratory scanner. The vertical, horizontal, and proximal contact errors were measured.

Results: Although all prostheses were seated on every model, the CF prostheses had greater vertical error, followed by PF.1, PF.2, and PF.3 prostheses, respectively. A similar pattern was observed for proximal contact error, where PF.3 was most superior. PF.3 prostheses had the least horizontal error than the other prostheses.

Conclusions: All interim prostheses experienced errors at the vertical, horizontal, and proximal surfaces, which can be attributed to deviations of the inserted implants. The PF of interim prosthesis with increased internal spacing for intraoral insertion appeared to reduce seating errors.

KEYWORDS

computer-guided surgery, deviation, immediate restoration, surgical guides

What is known

- Because of the accuracy of fully guided static computer-assisted implant surgery (sCAIS), it is possible to design and fabricate interim prosthesis prior to implant placement.

What this study adds

- The present study showed that interim prostheses with different designs and workflows can be produced to fit on implants placed via sCAIS. However, they experienced seating errors at the vertical, horizontal, and proximal surfaces.
- The fabrication of interim prosthesis for intraoral insertion appeared to reduce seating errors. This advantage was obvious with the incorporation of increased internal spacing between the prosthesis shell and prefabricated abutments.

1 | INTRODUCTION

Immediate implant restoration by interim prosthesis has significant benefits, such as immediate aesthetic and functional restorations, reduction of treatment duration, modeling of peri-implant soft tissue and development of emergence profile for definitive implant prosthesis.[1–6] However, fabricating a satisfactory interim prosthesis immediately following implant placement is time-consuming, technique sensitive, and may require an additional clinical visit.[1,2] Therefore, there is a consistent need for a reliable, simple, and efficient approach to fabricate implant immediate interim prosthesis.

Recent advancements in scanning and imaging technologies, digital planning, and computer-aided design and manufacturing (CAD/CAM) allowed for more precise implant planning and placement via static computer-assisted implant surgery (sCAIS).[7,8] Based on the virtual implant planning, surgical templates can be produced and used to control all the steps of osteotomy preparation and implant placement. The accuracy of this approach has been confirmed by numerous clinical and laboratory studies.[7,8] Subsequently, the high precision in implant placement further enabled designing and fabrication of interim prosthesis prior to implant placement.[1,2]

The combination of implant planning, sCAIS, and interim prosthesis virtual design and fabrication generated 2 workflows for immediate implant restoration: (1) complete fabrication (CF) of the interim prosthesis, where the interim prosthesis is fabricated to fit on sCAIS implant without any additional clinical step,[1,2,9] and (2) partial fabrication (PF) of the interim prosthesis, where a shell interim prosthesis is produced for intraoral cementation on prefabricated abutment attached on sCAIS implant.[3,10,11] CF of interim prosthesis has the advantages of simplicity and reduced insertion time.[2] However, since several studies indicated that implants placed by sCAIS experienced vertical and horizontal deviations from the planned implant position in the range of 1–2 mm,[8,12–16] interim prosthesis produced by CF may exhibit inevitable seating misfit on the placed implant in the form of lack of complete adaptation of prosthesis on the implant, interferences with proximal surfaces, alteration of prosthesis position, and occlusal errors. Clinical correction of these implant deviation-related misfit can be difficult and time-consuming. The PF of interim prosthesis has the potential advantage of compensating for inevitable deviations of sCAIS implants.[3] The incorporated internal space between the prosthesis and abutment can be increased to further improve the seating of the interim prosthesis. However, the cementation and cleaning process is still technique sensitive, will increase the duration of the surgical appointment, and may lead to displacement of the prosthesis. The authors are not aware of studies evaluating the effect of different designs and insertion workflows on the seating of interim prosthesis on immediate implants. Therefore, the aim of this study was to evaluate the seating accuracy of prefabricated prosthesis of different designs (level of spacing between the prosthesis and prefabricated abutments) and insertion workflows (CF or PF) for immediate restoration of implants placed via sCAIS. The evaluated variables were vertical errors, horizontal errors, and proximal contact errors. These variables were chosen because of their clinical relevance during insertion of prefabricated immediate prosthesis. Different prefabricated interim prosthesis designs and workflows were included: CF of interim prosthesis, PF of interim prosthesis with different magnitude of spacing between the prosthesis shell, and the prefabricated abutments. The null hypothesis was interim prosthesis fabricated by different designs and workflows have similar seating on implants placed via sCAIS.

2 | MATERIALS AND METHODS

2.1 | Implant planning and surgical template fabrication

A maxillary training model (Nissin Dental Products Inc., Kyoto, Japan) was modified to simulate a partially edentulous arch with missing four incisors. In addition to teeth removal, the ridge was contoured to resemble healed bone ridge without the soft tissue. The crest of the ridge had approximate width of 5.0 mm. The model was scanned with a laboratory surface scanner (Identica T300, Medit Identica, DT Technologies, Davenport, IA) to generate a virtual model for the design of the surgical template and the interim prosthesis (Figure 1). Duplicated model from resin mixed with barium sulfate was scanned by a cone-beam computed tomography (CBCT) unit to generate digital imaging and communications in medicine (DICOM) images for implant planning. The virtual model and DICOM images were imported to an implant planning software program (coDiagnostiX, Dental Wings, Montreal, Canada). Two implants were planned at the lateral incisor positions for subsequent restoration by screw-retained four-unit anterior prosthesis to replace all the missing incisors. The planned implants were bone-level Straumann implants (Straumann AG) with a 4.1 mm diameter and 10 mm length. The implants were planned to be placed 2 mm below the ridge.

Once the implant positions were confirmed, surgical template for sCAIS implant placement was designed to fit on the remaining teeth. Well-distributed seating windows were included in the design of the template (Figure 1B). A total of 15 surgical templates were produced by an SLA 3D printing unit (Formlabs Form 3, Formlabs, Somerville, MA, USA). Fully guided metal sleeves of 5 mm diameter from the same implant manufacturer (Straumann AG) were fitted in each template at the locations of the planned implants. The sleeves allowed for all the drilling, tapping, and implant placement steps to be completed without removing the surgical template.

2.2 | Interim prostheses fabrication

At the implant planning software, virtual prefabricated nonengaging stock abutments (Straumann Variobase) were selected. The model with the virtual abutments were imported to computer-aided design software (Exocad GmbH, Darmstadt, Germany) to design four-unit screw-retained implant immediate prosthesis (Figure 1C). The maxillary model with the designed prosthesis was imported in stereolithography format to serve as a reference model for subsequent seating accuracy evaluation. A total of four different screw-retained prosthesis groups were fabricated based on the design and insertion workflow. The first group was the CF of the interim prosthesis, where the interim prosthesis is fabricated with 100-μm spacing between the abutment and fitting surface, to accommodate for the resin cement. The spacing was even through the whole fitting surface, except on the shoulder of the abutment where the prosthesis was closely fitting. The abutments were attached to the prosthesis by laboratory cementation with composite resin cement (Variolink, Ivoclar Vivadent, Schaan, Liechtenstein) (Figure 2A). The remaining groups involved PF of the interim prosthesis, where the interim prosthesis shell (Figure 2B) was fabricated with different levels of spacing between the abutment and the fitting surface (Figure 2C–E). The PF prostheses were not connected to the abutment at the laboratory. Instead, they were planned for cementation on the abutments attached on the inserted implants. Three different PF prosthesis designs were included based on the level of internal spacing: 100 μm (PF.1), 200 μm (PF.2), and 300 μm (PF.3). All the PF prosthesis had accurate seating on the shoulder of the abutment. One prosthesis was produced for each group from composite resin by milling (DWX-51D, Roland DGA, Irvine, CA, United States) and was used as a reference jig for seating evaluation on implants placed on different models. The milling unit was calibrated before prostheses fabrication, and new milling burs were used. Every prosthesis was inspected to confirm it is free from manufacturing errors at the fitting and external surfaces. Apart from the cement spacing and insertion workflow, all prostheses had identical design.

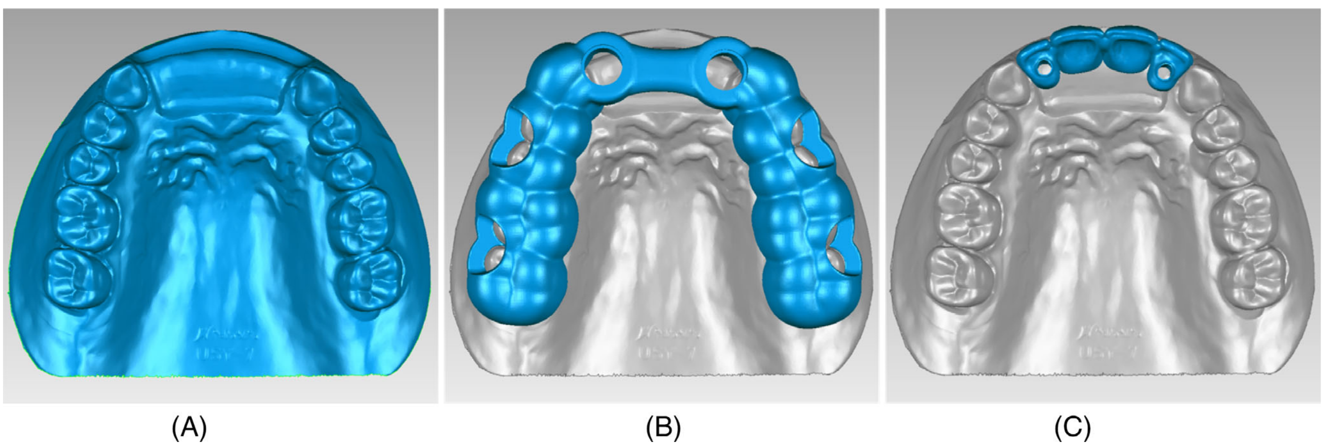

FIGURE 1 Virtual planning images. (A) The surgical model, (B) the designed surgical template, and (C) the planned interim screw-retained prosthesis that corresponds to the position of planned implants.

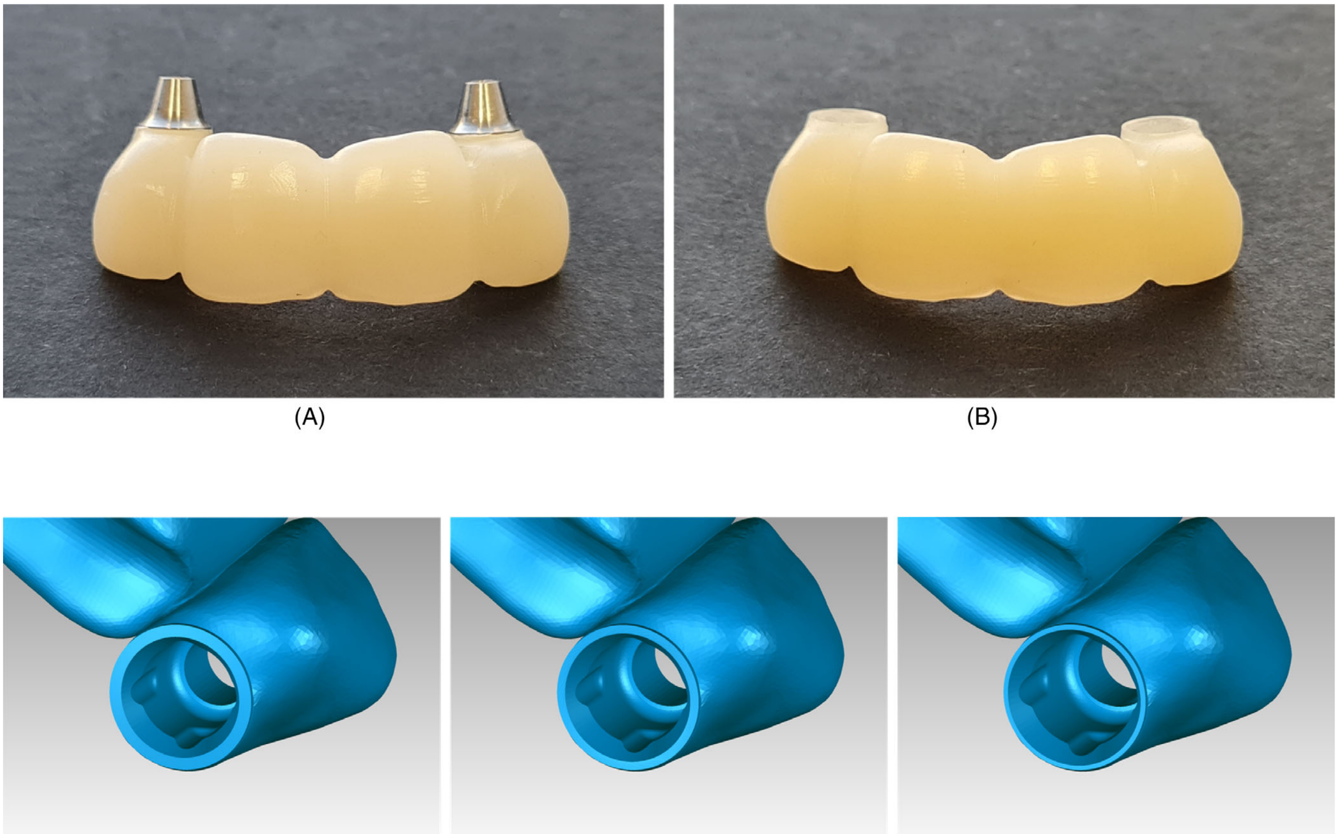

FIGURE 2 The included prostheses. (A) The complete fabrication prosthesis after attaching the prefabricated nonengaging abutment. (B) An example of a partial fabrication (PF) prosthesis shell. Three PF designs were included after altering the internal spacing between the fitting surface of the shell and the prefabricated abutment. (C) Internal space of 100 μm (PF.1). (D) Internal space of 200 μm (PF.2). (E) Internal space of 300 μm (PF.3). The spacing of the PF groups did not extend to the abutment shoulder.

FIGURE 3 The workflow for prosthesis insertion. (A) An example of the surgical model. (B) Seated surgical template. (C) Inserted implants via static computer-assisted implant surgery. (D) Seated interim prosthesis.

2.3 | Implant placement

The modified master training model was duplicated using laboratory silicone (Elite Double, Zhermack S.P.A., Badia Polesine RO, Italy) and produced from polyurethane material (Easycast, Barnes, NSW, Australia). A total of 15 surgical models were produced. For each surgical model, a different implant clinician inserted the two implants according to the sCAIS protocol of the implant system. With the template being fully seated on the teeth, the drilling steps, tapping, and implant placement were completed through the template (Figure 3). This ensured the implants were inserted in a close position to the planned virtual position. The final vertical position of the implants was achieved by the stop included at the inserted key. In order to simulate a clinical environment, the models were attached on a training phantom heads with opposing dentate mandibles.

2.4 | Seating accuracy evaluation

Each prosthesis was used to evaluate the seating accuracy on the inserted implants. This required complete seating of each prosthesis on the implants of each surgical model without interferences from any feature of the surgical model, such as peri-implant polyurethane material and proximal surfaces (Figure 4). Therefore, the prostheses were not adjusted during seating. Instead, any detected interferences were adjusted on the surgical model by rotary instrument. The aim was to ensure the interface between the prosthesis connections and implant platform can be visualized. Whenever indicated, the proximal surfaces on the teeth of the surgical models were minimally adjusted to allow for seating without interferences. The tightness and any binding spot at the proximal surfaces of the prosthesis were evaluated by shimstock foil (Coltene Whaledent, Altstätten, Switzerland). The retaining screws were tightened initially by hand followed by applying a torque value of 35 Ncm by a torque wrench. For the PF groups, the abutments were connected to the implants and tightened to 35 Ncm. The prostheses were attached to the abutments with temporary cement (Temp-Bond, Kerr, Brea, CA, USA). The prostheses were inserted with vertical pressure on the implant, and excess cement was removed. Temporary cement was used in this experiment to allow separation of the abutments from the prostheses and reseating them on the other surgical models. The prostheses were randomly seating on each surgical model.

After seating each prosthesis, the surgical model was scanned by the laboratory scanner to produce a virtual image of the surgical model with the seated prosthesis. Subsequently, each virtual image was superimposed against virtual reference model with the designed prosthesis by a metric software (Geomagic Control, 3D systems, Rock Hill, SC, United States). The superimposition involved locating four widely distributed points on the teeth of each model. The prosthesis was excluded from the superimposition process. The 3-dimensional alignment of the models was further refined by automated global registration. Eventually, the deviation between the planned interim prosthesis and the inserted interim prosthesis could be quantified.

At the superimposed models, three clinically relevant accuracy variables were measured: (1) vertical error, (2) horizontal error, and (3) proximal contact error. These variables were considered because they are influenced by the clinical seating and can affect aesthetics, occlusion, and the amount of necessary adjustments. The vertical error was the measured distance between the planned and inserted prostheses at the middle of the incisal edge of each incisor. Furthermore, the direction of vertical error was determined (supraincisal or infraincisal). Horizontally, the same points were used to measure the deviation at the horizontal plane. The direction of horizontal error was determined as buccal or lingual to the planned prosthesis. The proximal contact errors were measured at the proximal surfaces of each inserted prosthesis. The quality of the proximal contact was determined as open (gap between the prosthesis and adjacent tooth) or tight (virtual overlap between the prosthesis and adjacent tooth).

2.5 | Statistics

For every variable, the mean and standard deviations were calculated. After normality evaluation by the Shapiro–Wilk test, the Kruskal–Wallis test was implemented to evaluate the significance of difference among the groups. In case of significant difference, series of Mann–Whitney *U* tests were applied to test the difference between every two groups. For all statistical tests, the SPSS software package (SPSS

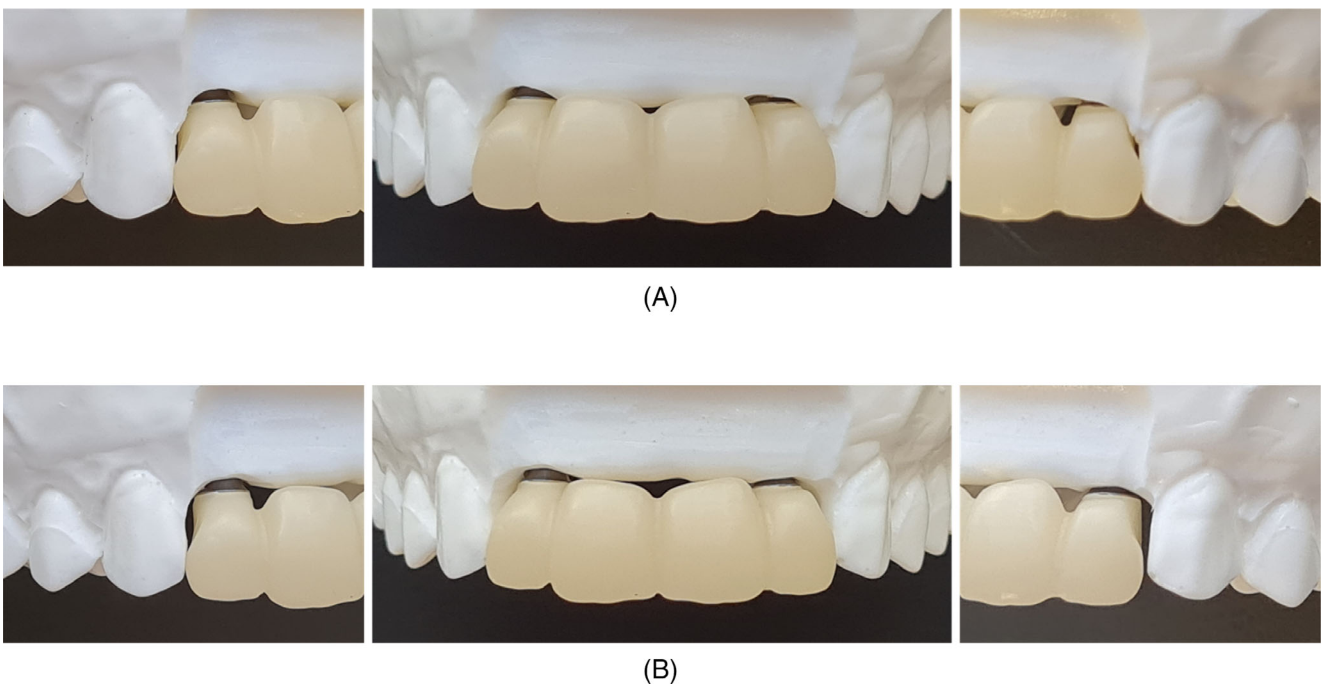

FIGURE 4 Illustrations of prosthesis insertion on different surgical models. (A) An example of clinically well-seated interim prosthesis with relatively accurate proximal contacts. (B) An example of seated prosthesis with errors in the form of supraincisal positioning and open proximal contacts (B). These errors appeared to be related to deviation of implant positioning.

for Windows, version 23, SPSS Inc., Chicago, USA) was used, and the level of significance was set at 0.05. For statistical tests, absolute values were evaluated. As a qualitative evaluation, vertical error, horizontal error, and proximal error values were plotted for every specimen along with the calculated accumulated error for every specimen (square root [(vertical error)^2 + (horizontal error)^2 + (proximal contact error)^2]).

3 | RESULTS

Regardless of prosthesis design, all of them were seated on the inserted implants. Table 1 summarizes the outcome of vertical error, horizontal error, and proximal contact error.

All prosthesis groups revealed vertical error predominantly of positive magnitude, where the inserted prosthesis tend to be at a more incisal position than the planned prosthesis (Figure 5A). This was very noticeable for the CF group. The CF group had higher vertical error magnitude (mean = 0.51 mm; SD = 0.41 mm), followed by PF.1 (mean = 0.30 mm; SD = 0.28 mm), PF.2 (mean = 0.25 mm; SD = 0.20 mm), and PF.3 (mean = 0.23 mm; SD = 0.21 mm), respectively. The difference among the groups was significant ($P < 0.01$). However, the pairwise comparison revealed that the CF group was significantly more inferior than the other groups ($P < 0.01$), whereas no significant difference was detected among all the PF groups.

Horizontally, the predominant form of error was positive, which is indicative of buccal positioning of the incisal edge (Figure 5B). The greatest horizontal error was detected for PF.2 (mean = 0.19 mm; SD = 0.14 mm), followed by PF.1 (mean = 0.17 mm; SD = 0.11 mm), CF (mean = 0.15 mm; SD = 0.11 mm), and PF.3 (mean = 0.10 mm; SD = 0.08 mm), respectively. Although the difference among the prosthesis designs was significant, the pairwise comparison indicated that the significant difference existed only between the PF.3 and the other groups ($P < 0.01$), where the PF.3 had significantly less horizontal error than the other groups.

PF.3 had the least proximal surface errors (mean = 0.09 mm; SD = 0.07 mm), followed by PF.2 (mean = 0.14 mm; SD = 0.10 mm), PF.1 (mean = 0.14 mm; SD = 0.11 mm), and CF (mean = 0.21 mm;

TABLE 1 Summary of vertical error, horizontal error, and proximal contact error.

Vertical error	CF	PF.1	PF.2	PF.3
Mean (mm)	0.51	0.30	0.25	0.23
SD (mm)	0.41	0.28	0.20	0.21
Maximum (mm)	1.90	1.10	0.98	0.95
Minimum (mm)	0.01	0.01	0.02	0.02
P values	All groups <0.01			
	CF versus PF.1 < 0.01		CF versus PF.2 < 0.01	
	CF versus PF.3 < 0.01		PF.1 versus PF.2 = 0.63	
	PF.1 versus PF.3 = 0.29		PF.2 versus PF.3 = 0.45	
Horizontal error				
Mean (mm)	0.15	0.17	0.19	0.10
SD (mm)	0.11	0.11	0.14	0.08
Maximum (mm)	0.44	0.50	0.46	0.30
Minimum (mm)	0.01	0.02	0.01	0.01
P values	All groups <0.01			
	CF versus PF.1 = 0.20	CF versus PF.2 = 0.22		
	CF versus PF.3 < 0.01	PF.1 versus PF.2 = 0.76		
	PF.1 versus PF.3 < 0.01	PF.2 versus PF.3 < 0.01		
Proximal contact error				
Mean (mm)	0.22	0.14	0.14	0.09
SD (mm)	0.16	0.11	0.10	0.07
Maximum (mm)	0.66	0.38	0.39	0.24
Minimum (mm)	0.04	0.01	0.01	0.01
P values	All groups <0.01			
	CF versus PF.1 = 0.05	CF versus PF.2 = 0.06		
	CF versus PF.3 < 0.01	PF.1 versus PF.2 = 0.08		
	PF.1 versus PF.3 = 0.22	PF.2 versus PF.3 = 0.08		

Abbreviations: CF, complete fabrication; PF, partial fabrication.

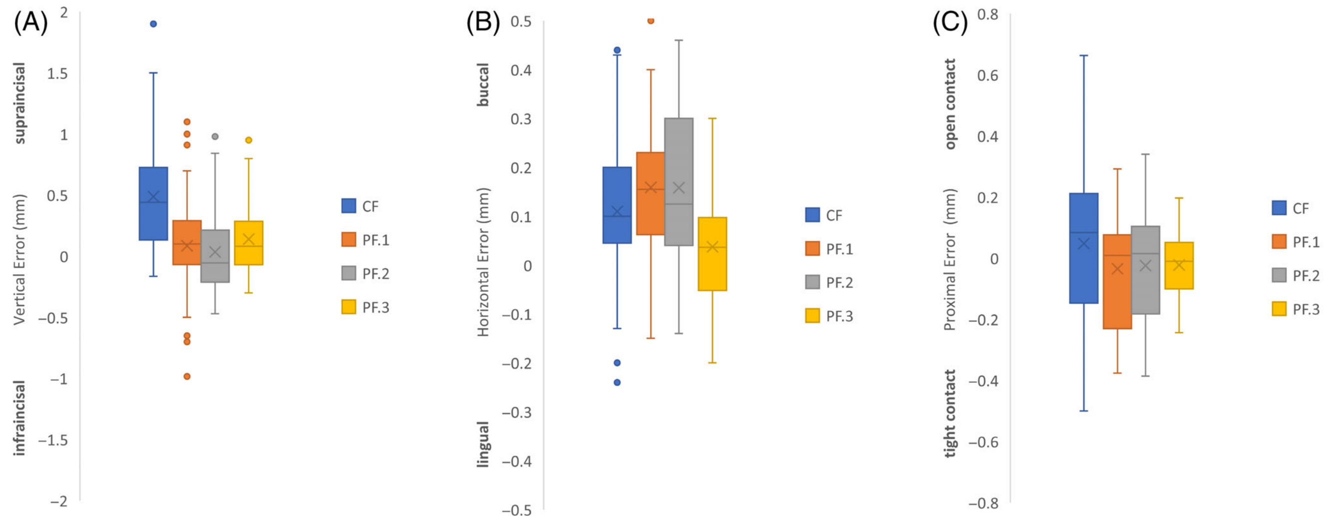

FIGURE 5 Box-and-Whisker plot diagrams illustrating the distribution of different errors. (A) Vertical error. (B) Horizontal error. (C) Proximal contact error. CF, complete fabrication; PF, partial fabrication.

SD = 0.16 mm), respectively. Significant difference was observed among the groups ($P < 0.01$). Specifically, this difference existed between the CF and PF.3 ($P < 0.01$). Figure 5C, indicated greater tendency for the CF group to suffer from greater tight and open proximal contacts than the other groups, whereas the PF.3 exhibited more ideal contacts.

Figure 6 illustrates the deviation of every specimen of each prosthesis group. Each specimen is represented by pairs of measurement for the right lateral the left lateral incisors of the interim prosthesis respectively. Overall, similar deviation pattern was observed among the different specimens, where the specimens that suffered from greatest errors also suffered from measurable errors across the different prosthesis designs and insertion workflows. In addition, the graphs support that the accumulated errors were greatest for CF group followed by PF.1, PF.2, and PF.3 groups, respectively. Thus, increasing the space between the fitting surface of the prosthesis and the prefabricated abutment can reduce the seating error.

4 | DISCUSSION

This study evaluated the feasibility of insertion of implant prefabricated immediate interim prosthesis prior to implant placement via sCAIS. To the knowledge of the authors, this study is the first to compare the seating of prefabricated interim prostheses produced by different designs and workflows. The vertical, horizontal, and proximal contact errors were evaluated as they provide a clear indication on the clinical implications of seating errors of the inserted prosthesis on two anterior implants. The fit of prosthesis on the implants was not evaluated because the titanium abutment interface was machined by the manufacturer and was not affected by prosthesis fabrication.[3,17] Since the titanium abutments were nonengaging and conical, complete seating is expected with torque application and inevitable distortion of the acrylic prosthesis and/or displacement of the inserted implants in the polyurethane model. Instead, misfit-related clinical variables were more relevant. The execution of implant placement by different operator may have contributed to variation in implant positioning. However, this methodology is closer to a clinical application as it prevented training a single operator to place implants in the same model. Considering that regardless of the design, all prostheses seated on the inserted implants, it can be stated that fabrication of interim prosthesis prior to sCAIS implant placement is feasible.[3–6,9] However, for all the variables, the errors of the different groups were measurable, and some designs and workflows had more superior seating than others. Specifically, PF interim prostheses for intraoral cementation following surgery appears to have a more superior seating, especially with larger internal spacing. Therefore, the null hypothesis that interim prosthesis fabricated by different designs and workflows have similar seating on implants placed via sCAIS was rejected.

The reliability of digital production tools of implant prostheses, such as scanning and CAD/CAM, has been confirmed by several laboratory studies.[17,18] Thus, errors in seating the interim prosthesis in the present study is primarily attributed to deviations in implant placements via the sCAIS protocol. Earlier studies reported that the errors of sCAIS implant placement can be up to 0.2 mm vertically[13,14] and 1.2 mm horizontally.[12,13,15,16] These errors are likely to be accumulated errors from every step of implant planning and placement,[7,8,19,20] such as CBCT acquisition and 3-dimensional segmentation, 3-dimensional printing of the surgical template,[21] tolerance between the drills and the different sleeves,[22–24] and fit of the surgical template on the teeth.[25] Implant placement deviation can further be caused by inconsistency of bone density or lack of primary stability.[12] Relating interim prosthesis seating errors to implant placement via sCAIS in the present study is clearly demonstrated at Figure 4, where the specimens that suffered from greatest error demonstrated greatest deviation for all prosthesis groups. In the present study, the incisal edges of the seated interim prostheses were

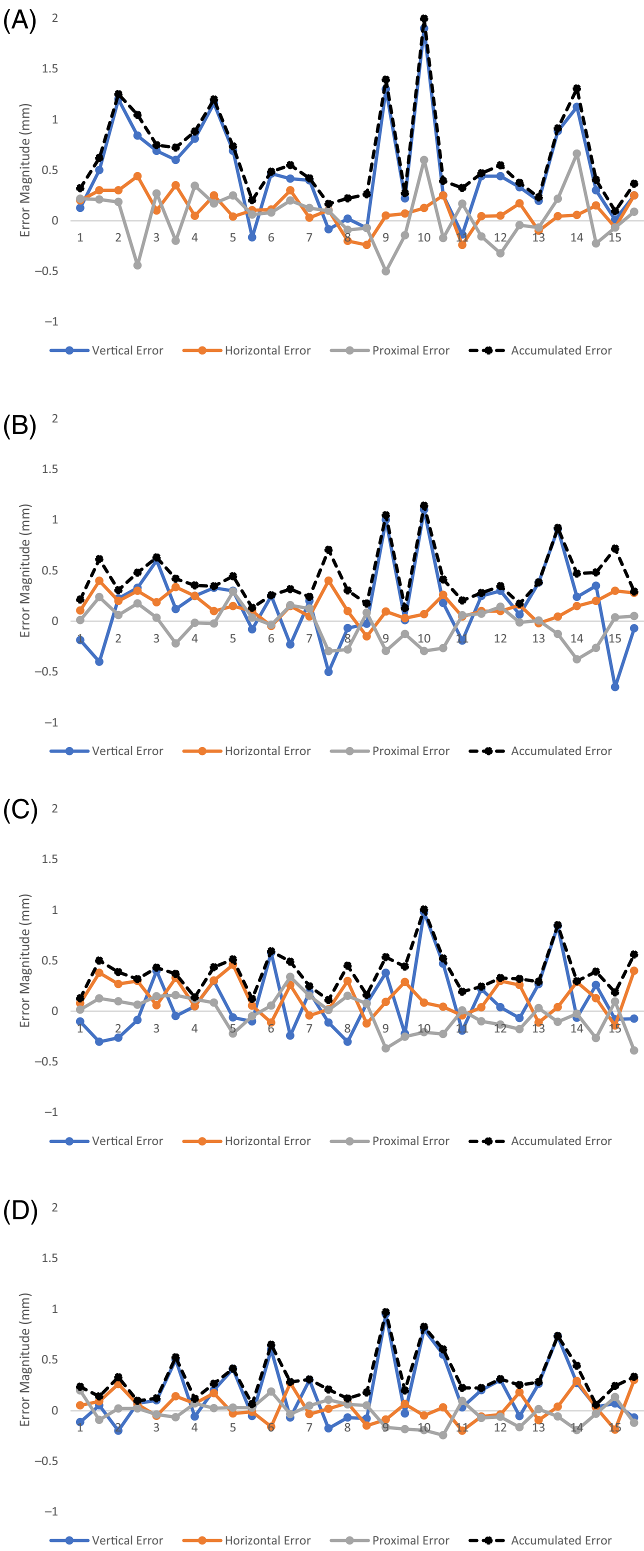

FIGURE 6 The distribution of vertical error, horizontal error, and proximal error values for every specimen along with the calculated accumulated error. (A), CF. (B), PF.1. (C), PF.2. (D), PF.3. CF, complete fabrication; PF, partial fabrication.

higher than the incisal edges of the planned prosthesis (range of 0.2–0.5 mm), which is consistent with previously published reports on vertical error of implants placed by sCAIS.[13,14] The supraocclusal implant position can be associated with error and friction of the surgical template on the teeth leading to incomplete seating of the template.[21,22,26,27] In addition, the presence of debris within the osteotomy of surgical plastic models may interfere with the complete placement of the implant. Horizontally, there was tendency for more labial positioning of the incisal edge (0.1–0.2 mm) which could be related to the labial tilting of implant body during insertion. This can be the result of template deformation during procedure after pressure application on the anterior segment of the seated template. This can further be exacerbated with the lack of hard tissue support for the template anteriorly.[19,28] Similarly, the mean proximal contact error was within 0.1 to 0.2 mm, which appears to be minimal for immediate interim prostheses. However, for some specimens with proximal contact errors greater than 0.5 mm, significant clinical adjustment is necessary in the form of reduction or addition.

This study revealed clear benefit of connecting interim prosthesis on prefabricated abutments intraorally, especially with increased spacing. The interim prostheses of the CF group were more supraincisally located than for PF groups, which could be the result of the inevitable premature binding between the nonengaging abutment and the implant connection.[9] Misfit at the prosthesis–implant connection interface will eventually lead to screw loosening or peri-implant tissue irritation.[29,30] On the contrary, the cement space and the intraoral cementation for the PF groups might have compensated for the deviation of implants placed via sCAIS or prosthesis manufacturing errors.[3,10,11] More importantly, the inevitable misfit at the prosthesis–abutment interface is compensated with intraoral cementation. Moreover, increasing the cement space between the prosthesis and the prefabricated abutments improved the seating accuracy, which could be the result of further compensation of sCAIS implant deviation. Eventually, the internal space allowed for more accurate vertical and horizontal placements and less interferences proximally.

Immediate implant restoration and loading by prefabricated prostheses prior to sCAIS surgery has been evaluated by earlier clinical studies.[2,29,30] Polara and colleagues[2] conducted a clinical study on single implants to compare digitally fabricated single implant interim crown before implant placement against conventional chairside interim crown after implant placement. They reported that insertion of digitally prefabricated interim crowns required approximately 5 times fewer adjustments and less chairside time than conventional chairside interim crowns. The superior clinical accuracy was found at the proximal surfaces, contour and adaptation to postextraction alveolar bone walls, and establishment of occlusal contacts.[2] On the contrary, technical complications were observed when multiple implants were immediately restored by whole arch prefabricated interim prostheses.[29,30] According to Johansson and colleagues,[29] out of 52 immediate whole arch prostheses, 2 prosthesis did not fit on the inserted implants, 10 prosthesis had significant connection problems between the prostheses and the multiunit abutments, and 3 prostheses required significant occlusal adjustments. Komiyama and colleagues[30] reported similar outcome after providing 31 immediate whole arch prefabricated prostheses, where 5 prostheses experienced misfit on the multiunit abutment, and 3 prostheses required extensive occlusal corrections. The technical complications that were reported by the clinical studies were attributed to the deviation of the placed implants from the planned implant position. Therefore, caution is recommended prior to routine application of this workflow.[29,30] Furthermore, clinicians executing this workflow should adhere to sCAIS protocol to maintain high level of precision of every involved step. In addition, since sCAIS implants will still experience 3-dimensional deviation,[8] the clinicians should be prepared to perform inevitable adjustments occlusally and interproximally. In general, occlusal and proximal adjustments are straightforward and routinely provided.[2] However, significant deviation may lead to misfit of prosthesis and significant aesthetic implications that are difficult and time-consuming to correct. The present study supports that connecting the prosthesis to prefabricated abutments or titanium bases clinically can be more predictable in compensating for implant deviation. However, despite the differences in seating accuracy of the different prosthesis groups, the clinical impact of the reported errors and how they affect the survival of the implant and interim prosthesis is yet to be determined. Although the increased internal cement spacing appears to improve the interim prosthesis seating, its impact on the retention and durability of the interim prosthesis requires further investigation. In addition, the impact of intraoral cementation of prosthesis on surgical duration and peri-implant health has to be evaluated.

Despite the attempt of the present study to simulate a clinical workflow, it could not replicate patient-related factors, such as saliva, bleeding, limited access and visibility, and movement.[7] Furthermore, the polyurethane surgical model has isotropic nature, and different density and hardness to natural bone. This may have influenced the ease and accuracy of implant placement.[9,15] The outcome of the present study is also influenced by the accuracy evaluation methodologies such as scanning, superimposition, software precision, and virtual measurements. In addition, a clear practicality evaluation, duration of treatment, cost-effectiveness, effectiveness of intraoral cementation, long term outcome of the different prosthesis designs need to be validated clinically. Therefore, it is encouraged to replicate the study in a clinical set-up.

5 | CONCLUSIONS

Within the limitations of this laboratory study, it can be concluded that the included designs and insertion workflows produced interim prostheses that can be seated on the inserted implants. All interim prosthesis groups experienced errors at the vertical, horizontal, and proximal surfaces, which can be attributed to deviations of the inserted implants. The PF of interim prosthesis for intraoral insertion appeared to reduce seating errors. This was obvious for the increased internal spacing between the prosthesis shell and prefabricated abutments.

AUTHOR CONTRIBUTIONS

Jaafar Abduo contributed to the concept/design, funding sourcing, data collection, data analysis/interpretation, drafting article, statistics, and approval of the article. Douglas Lau contributed to the design, data interpretation, critical revision and editing of article, and approval of the article.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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